Report on the British Society of Rheology mid-winter meeting on The Rheology of Foams and Emulsions, Royal School of Mines, Imperial College, London 10th - 11th December 2007

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British Society of Rheology mid-winter meeting on

The Rheology of Foams and Emulsions

Royal School of Mines, Imperial College, London

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The 2007 Mid-winter meeting of the British Society of Rheology (BSR) was held at the Department of Earth Science & Engineering, in the Royal School of Mines, Imperial College London on the 10th and 11th of December. The subject of the meeting was the rheology of foams and emulsions, with two aims: to provide a forum for the discussion of new results in the field and to introduce the subject to rheologists used to working with rather more "traditional" materials.

The programme attracted over 50 delegates from a range of academic disciplines and industries. Although the number of people who study the rheology of these highly structured fluids is perhaps small compared to those working with materials of a polymeric nature, it is clear that foams and emulsions are of interest to mathematicians, physicists, chemical engineers and food and materials scientists, among many others, and industries such as mining, petroleum and personal care.

A foam is a complex fluid with a rather precise internal structure: Plateau's rules indicate that soap films always meet three-fold in Plateau borders, the liquid-carrying channels that run between the bubbles. In turn, these borders meet tetrahedrally. The material, although *disordered*, is not *disorganized*. Before proceeding, we should also point out that concentrated emulsions have the same structure and behave in much the same way as foams, and for many purposes may even be preferable. This cellular structure gives an elastic response at low strain, and as strain, or strain-rate, increases, there is plastic yielding and then viscous flow. With the addition of surface chemistry, this is indeed a rich field for research.

The first lecture, given by Jan Cilliers (Imperial) on "How bubbles float the world economy", emphasized the importance of foams for ore-separation, and thus the effect that foam research can have on wealth creation. Cilliers described model experiments and simulations of the combined liquid, solid and gas motion in a flotation froth as the gangue flows up and over a weir to collect and purify the mineral particles. Although it is difficult to persuade mining companies to implement even the small changes to processes suggested by research, slight increases in efficiency have a remarkable effect on profit. Such improvements are even more worthwhile in the current climate, where the cost of minerals such as copper is becoming ever higher.

The following talk was partly motivated by another industrial application in which foam plays an important role: the use of foams for enhanced oil recovery. Sylvie Cohen-Addad (Paris Est) described the viscoelastic response of aqueous foams containing a proportion of solid particles. Even in the linear regime, the particles increase the shear modulus of the foam, and she described this in terms of a rigidity percolation model. The effect is confirmed by Surface Evolver (SE) simulations on ordered dry foams with solid inclusions.

A related presentation by Tudur Davies (Aberystwyth) described SE simulations of the interaction of circular particles descending through a foam under gravity. As well as stimulating discussion about what

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the forces are on a particle in a foam, he showed that the discs re-orient their line of centres to be parallel to the direction of gravity, as in elastic fluids.

Another reminder of industrial interest was Pete Wilde's work at the Institute of Food Research in Norwich on the stability of emulsions in foods, motivated by the desire to offer a lower fat product with the same taste. References to the growing obesity problem in the UK led a few of us to regret taking biscuits with our coffee. Wilde demonstrated that the rheology of the interface where the surfactant lies has a significant effect on sensory perception. This is reflected in the change in stability and creaming behaviour of emulsions as surface elasticity varies, although the mechanism for these changes is still not fully understood.

The theme of Richard Buscall's (MSACT Consulting) talk was similar: it is clear that the delay time for the collapse of emulsions and colloidal gels can be controlled, but those who say that the process is fully understood are surely mistaken. Buscall described how weakly attractive systems show a large range of delay times, dependent upon more than just the strength of the interaction.

In a similar manner, as the liquid content of a foam is increased, there comes a point at which the foam yields under its own weight. Ben Embley (Manchester) presented an analysis of what might be called a slump test, based upon the shape of a single Plateau border. The results should be useful in improved predictions of a convective instability, in which wet foams experiencing a constant liquid flow spontaneously undergo circulatory motion.

Two-dimensional (2D) foams, such as can be made by squeezing a foam between parallel glass plates until each bubble touches both plates, are usually considered objects of only academic curiosity. However, there is a great advantage to be gained by being able to see how each bubble is deforming during an experiment, and it is also the case that many 2D effects scale naturally to 3D. Nowhere is the beautiful microstructure of the material more apparent: films meet in threes and are curved in such a way as to indicate the pressure difference between neighbouring bubbles. Moreover, the internal strain can be "read" from an image. That is not to say, however, that 2D experiments are easy to perform.

Philippe Marmottant (Grenoble) showed us that foams and emulsions confined within microfluidic channels have not only high rheological reproducibility but offer a means to develop lab-on-a-chip type testing of small samples of gas or liquid. With applications in the pharmaceutical industry and in the detection of contaminants, this promises to be a growth area of research. Marmottant presented a study of instabilities between two possible bubble structures in a microfluidic device, in which the transition can be controlled with the liquid flow-rate and gas pressure.

For larger samples of 2D foams, further presentations can be divided loosely into shear and expansion. Many studies of this nature rely on foams as a model system for a large range of soft glassy materials. With this in mind, Alexandre Kabla (Cambridge) discussed the fluctuations in bubble velocity in a foam in a wide-gap Couette viscometer. In this geometry the topological changes, known as T1s, are localized close to the moving wall, in what is referred to as a shear band. Kabla presented a model that aims to describe the variation in shear stress for a given velocity profile. Aled Wyn (Aberystwyth) used SE simulations to show that in the linear Couette case, the width of the localized T1 region is proportional to the square root of bubble area disorder, measured through the second moment $\mu_2(A)$. Thus, in narrow foams with high disorder the T1s occur throughout the sample and the foam no longer exhibits shear banding. It remains to be seen whether these results apply to foams in a cylindrical geometry.

Kapil Krishan (UC Irvine) suggested that a proportion of these T1s may in some sense be reversible. That is, on reversing the direction of shear in his bubble raft experiment, parts of the foam structure returns to their initial state. This appears to conflict with the idea of topological changes being a manifestation of plasticity in a material, so that there are many avenues still to explore such as the extent to which a so-called plastic event changes the energy landscape of the foam.

Foams are used for explosion suppression, which perhaps inspired the work of Marco Mancini (Rennes): he described simulations and experiments where the area of a bubble in the centre of a large 2D cluster is varied cyclically. The response passes through a transient before reaching a periodic regime in which, as for Krishan, the topological changes are "reversible". The work also allows a prediction of the length-scale over which perturbations of the foam are dissipated.

The last part of the meeting was an opportunity for the BSR President, Phil Banfill, to award a number of the BSR's prizes. Foremost among these was the BSR Annual Award, given this year to Gerry Meeten

Figure 1: Gerry Meeten (Schlumberger) accepts the BSR Annual Award from President Phil Banfill.

of Schlumberger. Meeten gave an entertaining acceptance speech, reflecting on his career as an industrial rheologist (often considered a *rara avis*). He talked about his extension of Maxwell's work on birefringence, and squeeze flow experiments on a number of household products including foams, indicating the importance of micro-structure and wall slip to the interpretation of experimental results.

Another annual prize is the Vernon Harrison award, given to the best PhD thesis in rheology during the year. This year's winner was Tim Reis, who worked with Tim Phillips (Cardiff) on modelling multiphase flow with the lattice Boltzmann method. His prize-winner's address consisted of an extensive demonstration that the method is mathematically rigorous and in good agreement with existing results in a number of areas such as flow past a cylinder and coalescence in two-phase flow.

There were a number of excellent posters exhibited at the meeting, and TA Instruments generously offered a prize for the best. The judges were unanimous in awarding this to Line Do (Nottingham) for her work on the viscosity of reduced fat chocolate. She gets a travel bursary to attend a conference of her choice.

In conclusion, we thank all the speakers, poster presenters, and the sponsors for making this such an excellent meeting. Finally, we thank Denis Weaire (Dublin) for his entertaining words during the conference dinner, and offer our sincere hope that he didn't leave without his hat!

Figure 2: Tim Reis (UCL) receives the Vernon Harrison prize from BSR president Phil Banfill.

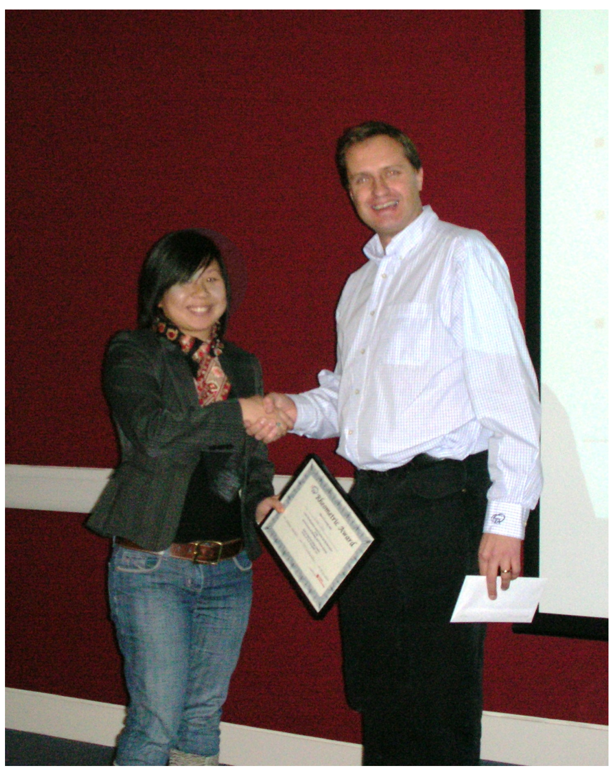

Figure 3: Line Do (Nottingham) accepts the Rheometric award for best poster from TA's Peter Hodder.